RESEARCH CHALLENGES IN SECONDARY PROCESSING OF METAL MATRIX COMPOSITES

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ABSTRACT

The presence of hard abrasive particles limits the machinability of MMCs and consequently they have limited applications. Both conventional and unconventional machining processes have been used for machining of MMCs. The factors that affect the machinability of MMCs are work material, percentage of reinforcement, tool material, tool profile and cutting parameters like cutting speed and feed rate. Unconventional machining processes like Electric discharge machining (EDM), powder mixed-EDM, wire-EDM, abrasive water jet machining have been employed in the recent year for machining of MMCs. However, there material removal rate is significantly less as compared to the conventional machining processes. The present research investigation explore the research challenges in the secondary processing of metal matrix composites particularly in drilling behavior of metal matrix composites.

Keywords: Metal Matrix Composites; Drilling; Secondary Processing; Aluminium

I INTRODUCTION

Secondary processing includes a process or combination of processes performed on the MMCs for making a useful product. Secondary processing can be broadly classified into two categories **(Figure 1)**

- Processes to make shape of the product
- Processes to alter the properties of the product.

The first category includes material removal (machining, shaping, drilling, milling, etc.) or material deformation (forging, bending, rolling, etc.) processes. In the former,(conventional machining process), the final shape of the product is achieved by removing extra material with the help of a cutting tool having relative motion with the workpiece. Plastic deformation of the material takes place during the material deformation processes to alter the shape of the product. Plastic deformation may be carried out at elevated temperature (above recrystallization temperature) or at room temperature under the application of an applied load.

The efforts have been made to develop near net shape manufacturing techniques for MMC products. But in many structural and engineering applications, machining becomes imperative to complete the assembly process. Therefore, for joining and assembling, machining processes such as drilling are often unavoidable. Drilling is often the last manufacturing process to be performed on a part before assembly. The hole making in MMCs by unconventional methods such as Electric Discharge Machining (EDM) necessitates higher set-up costs and results in lower productivity (Less Material Removal Rate). Therefore, conventional drilling is the most widely acceptable and frequently practiced machining operation for hole making in advanced materials such as MMCs leading to comparable quality characteristics.

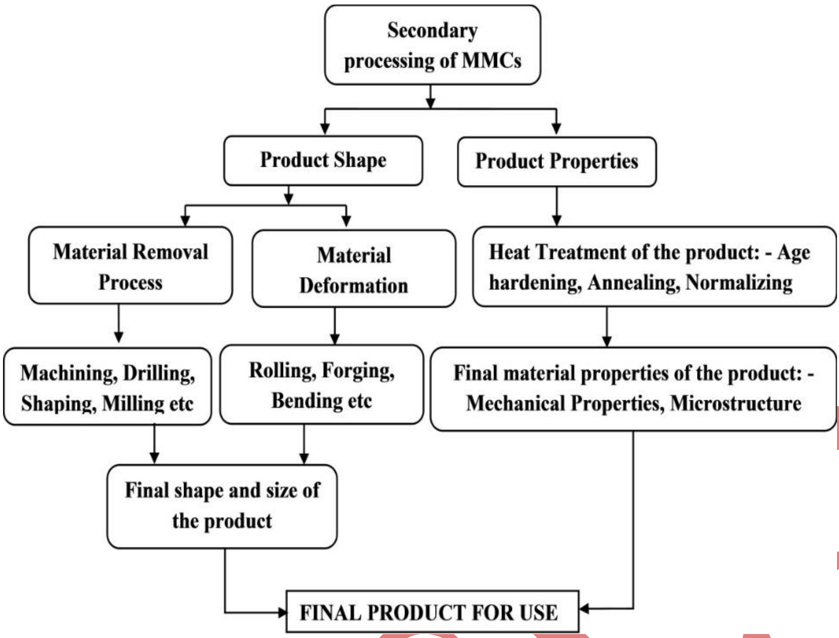

Figure 1 Classification of Secondary Processing of MMCs [1]

II MACHINING OF MMCS: CHALLENGES

The presence of hard abrasive particles limits the machinability of MMCs and consequently they have limited applications [2-3]. Both conventional and unconventional machining processes have been used for machining of MMCs. Conventional processes like turning, drilling and milling are used to produce the desired component. **Figure 2** presents the research trends for last ten years for the conventional drilling of MMCs. The factors that affect the machinability of MMCs are work material, percentage of reinforcement, tool material, tool profile and cutting parameters like cutting speed and feed rate [2,4-5]. These parameters also affect the drilling process output parameters like thrust force, torque, chip formation, surface roughness, and associated problems like built-up edge (BUE) formation, tool wear, burr formation, out of roundness etc. Unconventional machining processes like Electric discharge machining (EDM), powder mixed-EDM, wire-EDM, abrasive water jet machining have been employed in the recent year for machining of MMCs. However, there material removal rate is significantly less as compared to the conventional machining processes.

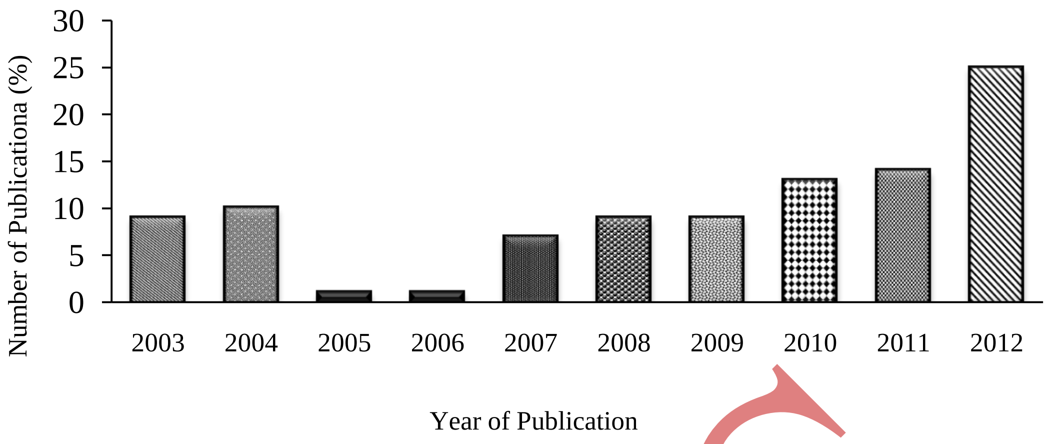

Figure 2 Research Contributions in Conventional Drilling of MMCs in the Last Decade

Different approaches have been recommended to attain improved machinability of MMCs. Coating was used on cutting tools to provide lubrication effect at tool-chip and tool work interface, to reduce the friction and tool wear as well as temperature at the cutting edge. Further the coating also improves the hot hardness of the tool materials. Low cutting speeds and uncoated cutting tools produced better surface finish compared to coated tools [3]. Addition of graphite to the MMCs helps in easy shearing of material, resulting in reduced tool wear and discontinuous chips [6].

Aluminium based silicon carbide particle (SiC) reinforced MMCs are nowadays finding numerous industrial applications. In these MMCs, the hard abrasive SiC causes excessive tool wear and poor surface finish of the machined part. Cutting tools like carbides, coated carbides, polycrystalline diamond (PCD) results in improved surface finish and reduced tool wear due to their better mechanical properties [7-8]. But these tools are costlier and more prone to breakage, even if there is a little vibration in machine tool or cutting tool. On the other hand, cutting tools like high speed steel (HSS) and coated HSS, will reach their limit of tool life within a short period of time, particularly in MMCs with higher volume fraction and coarser size reinforcement [3].

Therefore, there is an imminent need to explore the primary processing of MMCs to produce net-shape or near-net-shape of the products to avoid the problems associated with the secondary processing of MMCs. Selected secondary processes; particularly drilling is still required for joining and assembly of MMC products. Therefore, there is a necessity to further investigate the process of production and machinability of MMCs in order to produce industrial components of good quality at reasonable price.

III DRILLING OF METAL MATRIX COMPOSITES

Drilling of holes in MMCs with conventional tool lead to a novel set of challenges for researchers. The abrasive nature of the reinforcement causes high tool wear rate, increase in cutting forces and surface roughness of the drilled hole wall. The various machine tool parameters and cutting tool parameters (tool material, point angle, drill point geometry etc.) have been investigated to obtain an optimum combination of parameters for optimized output quality characteristics.

Tool wear is the major factor that influences the hole quality characteristics during drilling of MMCs, where the quality of the machined part produced is of primary important. Tool wear is influenced by the machine tool parameters and by the material properties (either workpiece or cutting tool) [2,10]. The machine tool parameters include feed rate, cutting speed, vibration-assisted drilling, type of cooling and lubrication. Certain uncontrollable parameters such as environmental conditions, temperature, humidity, vibration induced in the machine structure, and mental or physical fatigue of the worker also play a significant role in tool wear [9]. A large variety of tool materials have been investigated, such as HSS, high cobalt HSS, titanium nitride, tungsten carbide (WC), carbide-tipped HSS, solid carbide and polycrystalline diamond (PCD). In contrast to monolithic materials, in the case of drilling of MMCs, tool wear is inversely proportional to feed rate [11]. No uniform pattern of tool wear is observed with a change in cutting speed. The predominant mechanism of wear is abrasive wear, which leads to an increase in thrust force with an increase in tool wear. Built-up edges (BUEs) are observed on solid carbide drills and PCD drills on the chisel edge and flank edges. BUEs have both advantages and disadvantages. A BUE protects the cutting edge from wear as it makes an extra cutting edge on the main cutting edge. The developed BUE also causes an increase in thrust force and decrease in the surface finish of the workpiece. It can be concluded from the parametric evaluation of the machine tool parameters that cutting time and feed rate are the most predominant factors that affect tool wear during drilling of MMCs [12-13].

The hard ceramic reinforcing component in MMCs makes them difficult to machine and an attempt to do so leads to high drilling thrust force and torque [14]. The lowest forces are recorded for the experiments performed using PCD drills, followed by carbide and HSS tools. Torque values show the similar trend. Cutting speed has insignificant effect on the tool wear or on drilling forces. PCD drills produce lower drilling forces as compared to those generated by carbide-tipped drills. Drilling forces also depend on the hardness of the reinforcement. As the volume fraction of the reinforcement increases significantly, regardless of the tool material and workpiece material, both thrust force and torque are highly dependent on feed rate [8, 15]. A significant reduction in cutting forces is observed with the addition of 1-3 per cent graphite (hybrid composites). The most significant process parameters that significantly affect the cutting forces are feed rate and tool material. Cutting speed is insignificant in predicting the cutting forces during drilling of MMCs.

Surface roughness increases with an increase in feed rate but decreases with a decrease in cutting edge radius which may occur due to tool wear. At constant cutting speed, the surface roughness of the holes increase with increasing feed rate but does not change significantly with cutting speed. The lowest surface roughness is reported at the lowest feed rate and highest cutting speed. The increase in surface roughness with an increase in the feed rate results because the contact time between the tool and workpiece decreases, thus reducing the burnishing effect. The increase in feed rate also causes more serious BUEs on the tip of the cutting tool, which lead to an increase in surface roughness of the drilled hole wall. Cutting tool hardness is an important parameter in predicting surface roughness. Hard-carbide tools produce a better surface finish compared to that achieved when using HSS and TiN-coated HSS drills [3].

IV CONCLUSIONS

The following conclusions can be drawn on the present research investigation on secondary processing of metal matrix composites:-

1. A harder material other than HSS can be used as tool material. The PCD tools are expensive, increases the overall cost of the product.The cutting forces are dependent on the tool wear and tool hardness

2. Process modification (through cooling) led to decrease in cutting forces and tool wear. The Secondary reinforcement such as graphite also causes decrease in cutting forces
3. Drill point geometry plays a critical role in defining cutting forces and surface roughness.
4. Process modification such as ultrasonic vibration improves the quality characteristics of the process

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